L 25 Electricity and Magnetism [3]

- Electric circuits
  - what conducts electricity
  - what does and doesn't conduct electricity
- Current, voltage and resistance
  - Ohm's Law
  - Power loss due to heat produced in a resistor
- Simple circuit connections

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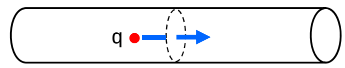
Electric current (symbol I)

- Electric current is the flow of electric charge q



- It is the amount of charge q that passes a given point in a wire in a time t:

$$I = \frac{q}{t}$$

- Current is measured in amperes
- 1 ampere (A) = 1 C / 1 s

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Examples

- A charge of 1 microcoulomb (10^{-6} C) passes through a wire every millisecond (10^{-3} s). What is the current in the wire?

  → I = q/t = 10^{-6} C/10^{-3} s = 10^{-6+3} s = 10^{-3} A = 1 milliamp = 1 mA

- A current of 3 A flows in a wire. Over a period of 1 minute, how much charge passes a given point in the wire?

  → q = I × t = 3 A × 60 s = 180 C

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Potential difference or Voltage (symbol V)

- To make water flow in a pipe, a pressure difference must be applied between the ends of the pipe
- A potential difference or *voltage* must be applied between the ends of a conductor to make the electrons flow
- Voltage is supplied by a battery (DC) or a an electrical outlet (AC)

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Electrical resistance (symbol R)

- Conductors have "free electrons" that roam around randomly → no current
- To push these free electrons through a conductor, i,e., to make a **current**, some external force must be applied to the conductor
- This external force must be continually applied because the electrons experience a **resistance** to motion, because they keep bumping into the atoms and slowing down
- The slowing down of the electrons is called "resistance" **(R)** and is measured in Ohms **(Ω)**
- The battery provides the external force **(voltage)** that keeps the electrons moving

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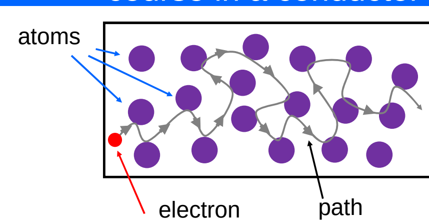
Electrons pass through an obstacle course in a conductor



- The **resistance (R)** is a measure of the degree to which the conductor impedes the flow of current
- We use the symbol  to represent the electrical resistance in a circuit

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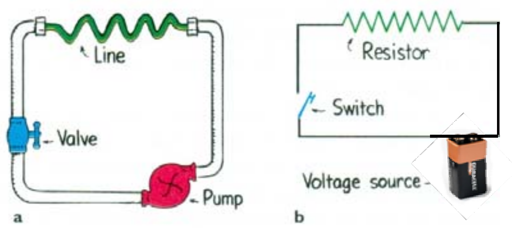
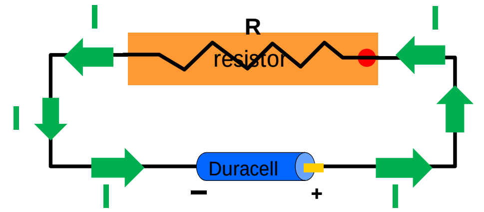
A battery is a charge pump

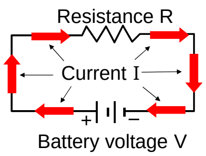


Direction of current flow



By convention, the current direction is taken as the direction that positive charges would flow, so it is *opposite* to the electron flow

Current, Voltage and Resistance: OHM'S LAW



R could represent, the resistance of a light bulb, hair dryer, coffee pot, vacuum cleaner, etc.

- **Ohm's law** is a relation between current (I), voltage (V) and resistance (R)
- **I = Voltage / Resistance = V / R**
  - V in volts (V), R in ohms (Ω), I in amps (A)
  - equivalent forms: **V = I R, I = V / R, R = V / I**

Examples

(1) If a 3 volt flashlight bulb has a resistance of 9 ohms, how much current will it draw?

➔ I = V / R = 3 V / 9 Ω = 1/3 A (Ampere)

(2) If a light bulb draws 2 A of current when connected to a 120 volt circuit, what is the resistance of the light bulb?

➔ R = V / I = 120 V / 2 A = 60 Ω (Ohms)

Heat produced in a resistor

- As we have seen before, friction causes heat
- The collisions between the electrons and the atoms in a conductor produce heat → wires get warm when they carry currents: in an electric stove this heat is used for cooking

- The amount of energy converted to heat each second is called the power loss in a resistor
- If the resistor has a voltage **V** across it and carries a current **I**, the electrical power converted to heat is given by
- **Power: P = I × V** = I ×(I × R) = **I^2 × R**

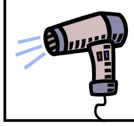
From Ohm's law

Heat produced in a resistor

- Power ➔ P = I ×V or I^2 × R
- Power is measured in **Watts = amps × volts**
- One Watt is one Joule per second
- Wires are rated for the maximum current that can be handled based on how hot it can get
- To carry more current you need wire of a larger diameter → this is called the wire gauge, the lower the gauge the more current it can carry
- Using extension cords can be dangerous!

examples

- How much current is drawn by a 60 Watt light bulb connected to a 120 V power line?
- **Solution:** P = 60 W = I ×V = I × 120
  so I = 0.5 Amps (A)
- What is the resistance of the bulb?
- **Solution:** V = I R→ 120 V = ½ A × R
  so R = 240 Ω, or R = V/I



How much current is used by a 2000 W hair dryer plugged into a 120 V power source?
→ P = I V → I = P / V = 2000W / 120 V ≈ 17 A

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extension cords and power strips

- extension cords are rated for maximum current → you must check that whatever is plugged into it will not draw more current than the cord can handle safely.
- power strips are also rated for maximum current → since they have multiple inputs you must check that the total current drawn by everything on it does not exceed the posted current rating

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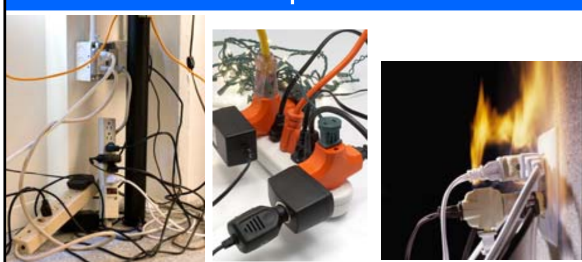
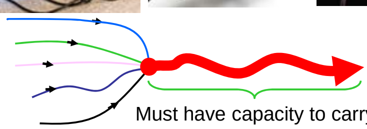
Unsafe practices





Must have capacity to carry all current

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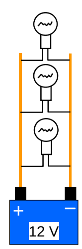
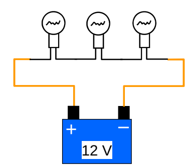
Parallel and Series Connections



- **Parallel connection**
- All bulbs have the same voltage = 12 V.
- The current provided by the battery is divided equally among the 3 light bulbs.



- **Series connection**
- The same current passes through each light bulb.
- Each bulb has a voltage of 4 V across it.

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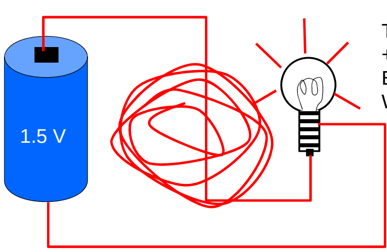
Simple direct current (DC) electric circuits

Exercise: given a battery, some wire and a light bulb, connect them so that the bulb is on.



The battery polarity +/- does not matter, Either way the bulb Will be on.

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Electric circuits - key points

- Electrons carry the current in a conductor
- a circuit provides a closed path for the electrons to circulate around
- Conductors have a property called resistance which impedes the flow of current
- the battery is like a pump that re-energizes the electrons each time they pass through it
- Ohm's law is the relation between current, voltage and resistance: **V = I R**
- When current passes through a wire, the wire heats up, the amount of heat energy produced each second (Power) is **P = I V = I^2 R**

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What is DC (direct current) ?

- With DC or direct current the current always flows in the same direction
- this is the type of current you get when you use a battery as the voltage source.
- the direction of the current depends on how you connect the battery
- the electricity that you get from the power company is not DC it is AC (alternating).
- We will discuss AC in the next lecture

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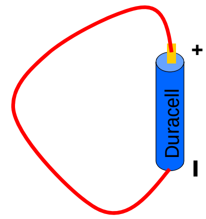
connecting batteries → do's and don'ts

don't connect a wire from the + side to the – side, this shorts out the battery and will make it get hot and will shorten its lifetime.



Do not do this

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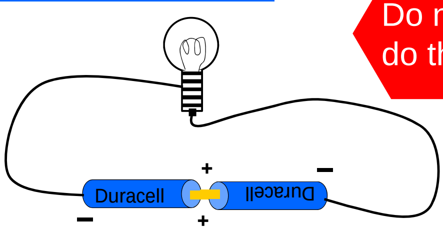
dueling batteries

Do not do this



The batteries are trying to push currents in opposite directions → they are working against each other. This does not work.

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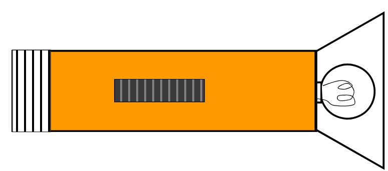
Proper battery connections

Connecting two 1.5 volt batteries gives like this gives 3.0 volts.



A Flashlight!

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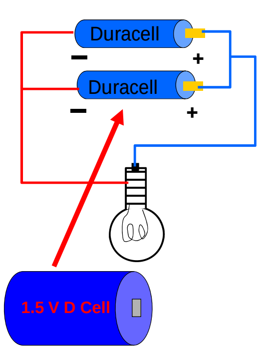
Batteries in parallel



This connection still gives 1.5 volts but since there are 2 batteries it will provide electrical current for a longer time

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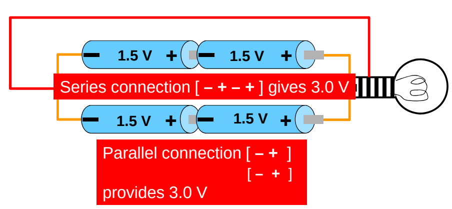
Longer lasting power series and parallel combination



This connection provides 3.0 volts and will provide power for a longer amount of time

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Disposable *vs.* Rechargeable Batteries

- Disposable batteries are electrochemical cells that convert chemical energy into electrical energy. Because the electrode materials are irreversible changed during discharge, they must be replaced
- Rechargeable batteries are also electro-chemical cells, but use materials in which the chemical reactions can be reversed in the recharging process

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